Fusion of MSCT imaging, Electro-Anatomical Mapping and Speckle Tracking Echocardiography for the characterization of local electro-mechanical delays in CRT optimization.

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Abstract

In this work, we sought to assist the optimization of Cardiac Resynchronization Therapy (CRT) through the characterization of electro-mechanical delays for each region of the Left Ventricle. This characterization is based on the fusion of electrical, mechanical and anatomical data acquired from Electro-Anatomical Mapping (EAM), Speckle Tracking Echocardiography (STE) and Multislice CT (MSCT) imaging, respectively.

Using MSCT as a reference, the first step is the registration of EAM 3D maps and STE 2D Contours on extracted MSCT LV-surfaces. After this registration step, local electrical and mechanical activation times can be displayed in the same space through 2D quantitative maps, therefore allowing the computation of local electro-mechanical delays. Local and global electro-mechanical delays from septal and lateral walls were calculated for three patients. The complementary information obtained may be useful for a better patient selection for CRT.

1. Introduction

Cardiac Resynchronization Therapy (CRT) has been shown to improve cardiovascular function and reduce mortality rates in a specific subpopulation of patients suffering from heart failure [1]. It consists on placing three pacing leads, one of which on the Left Ventricle (LV) through the coronary venous network. However, about one third of treated patients do not respond to the therapy. There are different ways to optimize CRT. One would be to improve patient selection, another would be to optimize the pacing sites. This optimization could benefit from the characterization of electro-mechanical delays for each region of the Left Ventricle (LV). This study aims to perform this characterization by the fusion of electrical, mechanical and anatomical data acquired from Electro-Anatomical Mapping (EAM), Speckle Tracking Echocardiography (STE) and Multislice CT (MSCT) imaging, respectively.

EAM is a medical procedure consisting in the measurement of the local electrical activity of the endocardium wall: a moving probe measures the spontaneaous (no stimulations) electrical activity, which is compared to a reference signal, giving the Local Activation Time (LAT) delays. Thus EAM provides 3D anatomical points of the LV and their associated LAT delays. In recent work [2], EAM probe has been used also to measure displacements. STE produces 2D contours of the LV manually segmented by the echocardiologist as well as their displacements and strains.

In previous works [3], we described a semi-automatic rigid method for the fusion of EAM and MSCT LV-surfaces. We present here an automatic rigid registration of 2D STE contours and MSCT LV-surfaces. The algorithm searches for the echographic plane in the MSCT space. The STE data available in this study are a 2D+T modality, whereas MSCT is 3D+T. In many works, registration of STE and MSCT is done considering information on voxels, for instance mutual information [4, 5]. As we have access to segmented 2D contours and 3D surfaces, the use of geometrical information is chosen here. This registration step is based on the minimization of a metric calculated between STE contours and MSCT surfaces. This metric computes a mean square distance between two contours and weights the value according to anatomical *a priori* knowledge (orthogonality between great axis, distance between apex, and 4 or 2 chambers views). The minimization of this metric is done by gradient descent.

After registration, MSCT, EAM and STE stand in a common space. We propose means to compare local electrical and mechanical activation through the use of 2D quantitative maps. We present here a detailed description of the STE and MSCT registration algorithm. Using this method, local electro-mechanical delays (EMD) on three patients are given.

We present in this paper a brief description of the data

(MSCT, EAM and STE), the necessary registration steps before results and discussion on the comparison of local and global EMD.

2. Data acquisition and pre-processing

As a part of the IMOP (IMaging for Optimisation of biventricular Pacing) research Project, this study has yet been possible on three patients with the following data.

The MSCT database was acquired with a Multi-Slice Computerized Tomography scanner (*General Electric Healthcare* LightSpeed VCT 64-slice Scanner) providing reconstructed volumes by ECG post-synchronization. The segmentation of the left endocardium is realized using a fuzzy connectedness algorithm [6, 7]. Using marching cubes [8], a 3D surface (refered as S_{CT}) containing the LV, the left atrium and the beginning of the aorta is reconstructed (fig. 1).

EAM data (*Saint Jude Medical's* EnSite System) are composed of 3D anatomical points that form a LV-Surface (used for registration), measurement points and their associated LAT delays (fig. 1). LAT delays are, for each measurement point, the time difference between the local electrical activity peak and the electrical activity peak of a reference signal (*e.g.* electrical activity in the left atrium).

The STE database contains 2D+T images in which the endocardium wall has been manually segmented. On each of these 2D contours, displacements have been recorded and 6 segments have been selected for strain measurement (fig. 1).

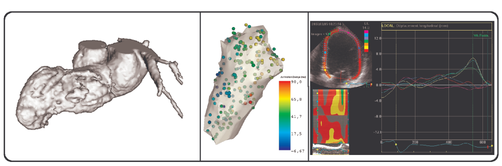

Figure 1. From left to right : MSCT segmented 3D surfaces, EAM data, STE data

3. Methods

As previously mentioned, a necessary first step to provide local EMD, is to combine electrical and mechanical data in a common anatomical space. MSCT has been chosen as the anatomical reference as it offers (i) a reliable anatomical representation (ii) the possibility to study cardiac function and (iii) a detailed description of the venous network [9] that may be useful for lead implantation planning.

3.1. EAM and MSCT data fusion

The fusion method of EAM and MSCT data relies on three steps: (1) from MSCT data, cardiac left chambers segmentation and LV separation from other anatomical structures by the automatic search of the atrioventricular plane; (2) spatial 3D surface rigid registration in order to get the two modalities in the same spatial referential. In a first step, a rigid transformation that fits EAM LV-surface's apex and great axis on MSCT LV-surface's apex and great axis is applied. Then, with geometrical considerations (*e.g.* position of the aorta), a rotation around the great axis is interactively applied; (3) combination of electrical and anatomical data representation to give an adapted tool to clinical routine.

3.2. Data registration

The method consists on defining, in the MSCT space, the echocardiographic probe plane. This defines a plane by 6 parameters (origin $O_{STE} = (x_O, y_O, z_O)$ and normal $\overrightarrow{N_{STE}} = (x_N, y_N, z_N)$). We use one last parameter (rotation θ_N around plane's normal) for the definition of STE contours. A parameter vector X is thus defined as: $X = [x_O, y_O, z_O, x_N, y_N, z_N, \theta_N]$.

3.2.1. Metric calculation

We extract from the MSCT surface a 2D contour corresponding to the echocardiographic plane in order to be able to compare two similar curves (C_1 and C_2). Let $\overrightarrow{N_{1_i}}$ be the normal on point $M_i \in C_1$, $p_1(M_i) \in C_2$ be the normal projection of M_i and $\overrightarrow{N_{2_i}}$ its associated normal. We then define:

$$d_1(C_1, C_2) = \sum_{M_i \in C_1} \left\| \overrightarrow{M_i p_1(M_i)} \right\| + \left\| \overrightarrow{N_{1_i}} \wedge \overrightarrow{N_{2_i}} \right\| \quad (1)$$

where the second term denotes the regularity between the two curves. $d_2(C_2, C_1)$ is defined the same way. To have a symetric metric, we define :

$$D(C_1, C_2) = \frac{1}{2} \left(d_1(C_1, C_2) + d_2(C_2, C_1) \right) \quad (2)$$

3.2.2. Weight calculation

To consider *a priori* knowledge and increase registration's accuracy, the metric is multiplied by a weight describing anatomical correspondences between modalities. For instance, for both modalities the apex is estimated and the distance t_{ap} separating both apical points in space is calculated. This distance t_{ap} is a function of X. Since uncertainties remain on apex location, a confidence interval

$[-\sigma_{ap}, \sigma_{ap}]$ is chosen for t_{ap}. For X and considering t_{ap}, $D(X)$ is multiplied by $W_{ap}(X)$:

$$W_{ap}: \quad \mathbf{R^7} \rightarrow [\mathbf{1}, \mathbf{1.5}]$$
$$X \mapsto \begin{cases} \xi{=}1.5\left[1-\exp\left(-\frac{t_{ap}(X)^2}{2\sigma^2}\right)\right] & \text{if } \xi{>}1 \\ 1 & \text{otherwise} \end{cases} \tag{3}$$

The metric shows local minima and the global minimum might not be the desired solution. The proposed ponderation gives more credit to a minimum located in the confidence interval. We choose, $\sigma_{ap} = 20\text{mm}$. Two other similar weights are computed: one penalizing an irrealistic angle between the two great axis W_{GA}, the other penalizing a position of the STE plane too far from an estimated 4 chambers view W_{view}. All weight functions W_X are similar (Eq. 3) except for the two parameters t_X and σ_X. Respectively, we took $\sigma_{GA} = 10°$ and $\sigma_{view} = 25°$. For a given X, the ponderation proposed is the product of those weights: $W = W_{ap}W_{GA}W_{view}$. This way, other weights could be added if more *a priori* information is known.

By minimization of $W(X)D(X)$ (gradient descent method), the parameters $\hat{X}$ defining the echocardiographic plane in the scanner base are estimated allowing the comparison of local electrical and mechanical activation times in the same space.

3.3. Local EMD estimation

The time reference on STE is the beginning of QRS wave (given by the clinician) on the surface ECG, therefore, in order to synchronize both modalities, we selected this time instant on the EAM ECG. On EAM, the time reference used to measure LAT is the peak of the reference signal. Therefore, the difference between this peak and the beginning of QRS is added to EAM measurements. Electro-mechanical delays are measured beween an electrical activity and a mechanical response. Mechanical responses are measured using 2D strain peaks for available cardiac segments on STE. Concerning electrical activity, the beginning of the QRS wave of the surface ECG is used for global EMD while negative peak of local activity signal (EAM data) is used for local EMD (Fig. 2).

4. Results

After registration, spontaneaous electrical LAT and mechanical local activation are compared through the use of 2D quantitative maps. For one patient, displacements of US contour points (for available echocardiographic views) are displayed in regards of their electrical activation times (fig. 3). On a healthy heart, the basal-septal segment is the first to be electrically activated, the impulse then propagates to the basal-lateral segment. In our study, on the 4 chambers view, the mechanical activation on the septum

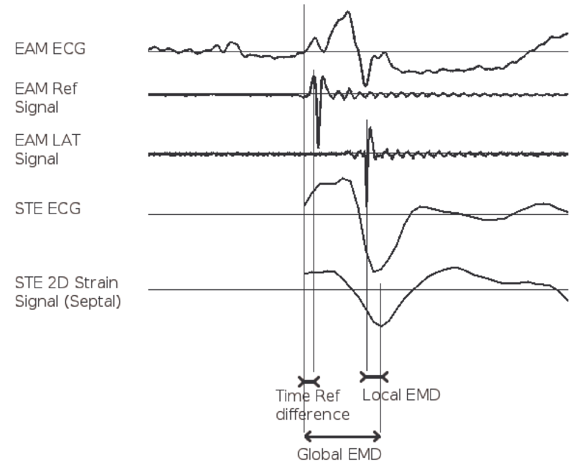

Figure 2. Local EMD / Global EMD estimation from ECG , LAT and 2D strain signals for EAM and STE.

wall occurs before the lateral wall (more significant for radial movement). On the 2 chambers view, the electrical activity occurs almost at the same time for all segments.

2D Strain is not influenced by passive movements whereas displacement measures are. Therefore, it is more adapted for mechanical studies and its access allows the computation of local and global EMD. Those measurements have been computed for septal and lateral walls on 3 different patients, suffering from severe asynchronism (Table 1). For each studied patients, the difference between local and global delays is greater on the lateral wall than on the septal wall. These observations were physiologically expected because the local electrical activation on the septum corresponds to the beginning of the QRS wave (reference for global EMD) while on the lateral wall it corresponds to the end of the QRS wave.

EMD (ms)	Mid-Basal Septal	Mid-Basal Lateral
P01 Global	63	410
P01 Local	6	298
P02 Global	75	429
P02 Local	2	299
P03 Global	116	478
P03 Local	25	352

Table 1. Comparison between local and global electro-mechanical delays for three different patients.

5. Discussion and conclusions

A fusion method has been introduced and applied to the left ventricle in MSCT imaging, EAM and STE. In previous works, we described a semi-automatic method for MSCT imaging and EAM data fusion. An automatic registration method for reconstructed MSCT 3D surfaces and 2D STE contours was developed, using anatomical *a pri-*

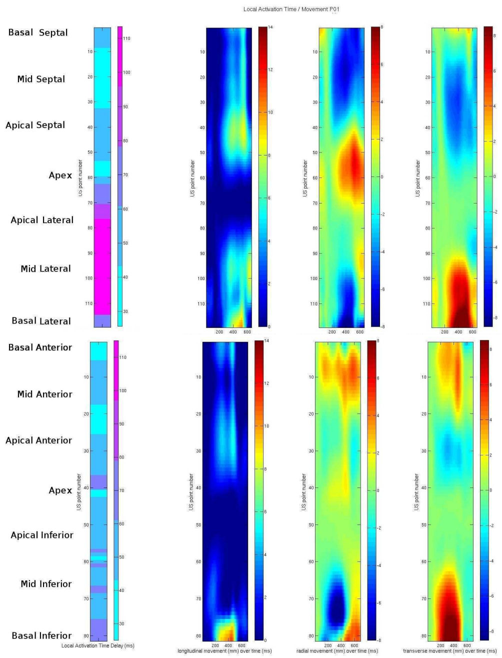

Figure 3. Top: 4 chambers view, bottom: 2 chambers view. From left to right: LAT delays, Longitudinal displacements, radial displacements, transverse displacements. Maps are created as if each contour was unfolded and displayed on a vertical line over time on a cycle.

ori knowledge to ease convergence towards an appropriate result. This work shows the feasibility of using mechanical and electrical LAT to provide a better characterization of EMD on the LV. We believe that local electro-mechanical studies could bring complementary readings on patients suffering from heart failure, as suggested by other works using model-based analysis of strain data [10]. Indeed, not only mechanical dysfunctions but electrical or electro-mechanical dysfunctions could be revealed (*e.g.* passive displacement due to the contraction of other segments). Yet, concerning 2D strain, "time to peak" measures are not necessarily the best indicators of ventricular asynchronism. In fact, clinicians tend to study 2D strain curves shapes and peaks chronicity. Samol *et al.* [11] show the correlation between interventricular asynchrony and QRS integral. Having access to local electrical activity is a great opportunity to finding electro-mechanical indicators for CRT optimization.

Acknowledgements

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